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BIDIRECTIONAL BIPOLAR STATIC INDUCTION TRANSISTOR

The invention relates to microelectronics and more particularly to bidirectional bipolar static induction transistor. Any device, according to the present invention can be latched. However, if the latch current of the device exceeds the maximum permissible constant current, such device can be considered as the device without latching, i.e. the transistor.

background of the invention

There exists a vertical JFET, in which a gate and a channel are formed by the implantation of an impurity in a doped epitaxial layer through mask – a doped polysilicon source electrode[1]. The method provides forming of the transistor with channel thickness equals of about $10 \cdot 10^{-5}$ cm.

There exists a bipolar static induction transistor comprising elements of a bipolar static induction transistor: a gate, a source and a channel – on one of the sides of the substrate, and elements of a onejunction transistor: an emitter and a base (drain) – on the other [2]. This transistor has high current density and can switch relatively high power.

There exists a bipolar transistor, which has structure actually comprising two bipolar transistors and which can operate in alternating-voltage circuit [3].

There exists a vertical bidirectional MOS-type semiconductor device, that facilitates controlling a DC current and an AC current at a relatively low on-voltage[4]. The bidirectional MOS-type semiconductor device includes a first n-channel IGBT and a second n-channel IGBT. The first n-channel IGBT is formed of n+ type source 102, p-type base 103, an n.sup.- type substrate 101 and p-type anode 104. The second n-channel IGBT is formed of n+ type source 105, p-type base 104, an n.sup.- type substrate 101 and p-type anode 103. The operation of the second n-channel IGBT is the inversion of the operation of the first n-channel IGBT. The first n-channel IGBT makes a current flow from a first terminal 106 to a second terminal 107. The second n-channel IGBT makes a current flow from second terminal 107 to first terminal 106.

summary of the invention

The advantage of the offered transistor is that it have a high technical characteristics: a high current density, a high switch power and a very low on-voltage. It can operates in both constant-voltage circuits and alternating-voltage circuits, for example 120 V and more (breakdown voltage is as a rule $1+2$ kV), which means that it can be all three closed, open or latch at any voltage polarity. The thick channel connected to a separate electrode provides increasing latch current of the transistor and simplification of many circuits, which use the transistor.

This result is achieved by disposing elements of a bipolar mode static induction transistor on both major surfaces of a lightly doped silicon monocrystal substrate with a long hole lifetime having a donor concentration of about $10 \cdot 10^{14}$ cm.⁻³:

an epitaxial layer, a gate, channels, sources, gate and source electrodes;
 impurity concentration near said gates is high enough; said gate, said sources and said channels are disposed in said epitaxial layer; donor concentration of said epitaxial layer equals of about 10^{17} cm^{-3} ;
 one channel of the multielement structure is thicker than the other normally-off channels;
 said channel is connected to separate electrode;
 said source electrodes are formed of n⁺-type polysilicon.

The offered transistors can be applied for generation, transmission and use of electric energy within a very broad range of power: from the control of electrical soldering to the control of most powerful turbogenerators and thermonuclear stations. They are effective for designing electronic transformers, power supply units, and controllable power transmission lines. These transistors can be most widely used in the devices aimed at defending people from electric shock. They can also be used in a high speed information transmitter on an electric network. They can also be used in systems with the unipolar power supply transmitting energy in both directions – both from a source to a load (rasonator) and from the load to the source. It will make it possible to increase circuit efficiency with the voltage drop between a drain and source of the open transistor as a rule not exceeding 0.5 V and, if necessary, it can be highly close to zero.

For manufacturing offered transistors one uses a lightly doped n⁺-type substrate of monocrystal silicon with a long hole lifetime ($1 \cdot 10^{-4}$ sec). The structure of the offered transistor is symmetric which means that on both sides of the substrate with the donor concentration of about 10^{14} cm^{-3} there are the epitaxial layer with the donor concentration of about 10^{17} cm^{-3} , areas of a p⁺ gate, a n⁺ sources, an ordinary channel and a thick channel as well as the electrodes of gate and sources (drains). Owing to the structure symmetry, the output voltage-current characteristics of the transistor are symmetric and are in the first and the third quadrants. Because of this, the source and drain of the transistor can change places and the transistor can operate in alternating voltage circuits of supply pressure of 120 V and more which simplifies many circuits and besides the transistor can be applied in the circuits which cannot be produced with any other types of transistors.

If threshold voltage of the channel near the drain equal to about 0.6 volt the device can not be closed; open or latched only. If threshold voltage below than 0.5 volt the device can maintain high voltage if applied voltage have been changed slowly. If the threshold voltage equal to approximately 0.2 volt device operates as transistor. The threshold voltages of thick channels of transistor can be a little higher than zero volt or below zero.

Let potentials of the gates are equal to potentials of the source and drain accordingly. Let applied voltage have been increased abruptly. The electrons flowing to the drain electrode can cause emission of the holes from the gate, disposed near the drain. The holes flow to the gate, disposed near the source. Part of the holes flow into the channel and causes the flow of the electrons to the drain. So, there is a positive feedback in the device. Device is latched. On-voltage of the latched device is more on about 0.7V than on-voltage of the open transistor. The latch current depends on the channel resistance for the electron current, in the first place from a donor concentration in the channels, a channel length, a threshold voltage.

Introduced in the structure the thick channel provides increasing of the latch current. A threshold voltage of the thick channel is lower than that of the ordinary channel. Algorithm of control of the offered transistor under typical circumstances is more complicated than that of the transistor described above [2]. Though the structure of the transistor is symmetric the operating duty of the channel that is near the drain of the transistor essentially differs from the operating duty of the channel that is near its source. The electrical field reduces the concentration of holes in the former and increases their concentration in the latter. Owing to this, the hole concentration along an axis perpendicular to surface is trapezoidal in zero approximation. It puts certain restrictions both on the design parameters of BBSIT and on designing of circuits in which these transistors are applied.

To prevent the feedback it is necessary to provide so that electrons might flow to the

drain free. It depends both on a control circuit and on the construction of the transistor. The construction of the transistor provides the way for electrons to the drain through the thick channel while transistor is closed or is being switched off. The potential of the thick channel drain electrode has to be positive or zero or little negative relative to the potential of the drain electrode of ordinary channel. The high drain voltage extracts electrons from the thick channel which is disposed near the source. The potential of the thick channel source electrode has to be positive so that the thick channel is closed. It is allowed that the potential of the thick channel source electrode might equal to zero.

When polarity of the applied voltage changes, the source and drain change places, and the potentials of the thick channel electrodes should be changed accordingly so as the transistor is to remain closed. In this case the transistor can maintain voltages up to several kilovolt depending on parameters of the lightly doped area, in the first place from the thickness and number of donors between the gates as well as from performance of the channel.

Another voltage on the gates equal to about 0.8 V relatively of the source and drain which are nearby. It provides the opening of the channels and hole emission into the channels and lightly doped area. The emission of holes to the lightly doped area is followed by electrons from the transistor source which makes the hole concentration and electron concentration practically the same and may reach the magnitude of $10 \cdot 10^{17} + 10 \cdot 10^{18} \text{ cm}^{-3}$ and more; resistance of the transistor drops abruptly due to conductivity modulation and the voltage between the drain and source of the transistor as a rule does not exceed 0.5 V at current density $\approx 1000 \text{ A cm}^{-2}$ (the thickness of the substrate is decreased by etching). There is a smoothly lowering voltage on the gate which is near the source of the transistor during the switching of the transistor from on-condition to off-condition, owing to extraction. To decrease the loss of switching off the voltage on the gate which is near the drain of the transistor should be remain during the first part of time of switching off (approximately $10 \cdot 10^{-6} \text{ sec}$). It is desirable a hole emission into the lightly doped area during first part of time of switching off (extraction out holes exceed emission into one).

There are different operating duties of transistor on-condition:

1. Basic duty. A hole concentration near the source of the transistor is essentially bigger than the one near the drain (trapezoidal distribution). Owing to this, a hole current consists both a hole diffusion, directed from the source to the drain and a hole drift, directed from the drain to the source. The hole current can be for example equal to zero (zero approximation). An electron concentration approximately equal to the hole concentration. An electron diffusion current and the electron drift current flow in the same direction – from the drain to the source. So almost all the current is transferred by electrons on the way of which there are almost no potential barriers and besides on the greatest part of the way the concentration of impurity is small and, correspondingly, the dispersal of carriers on impurities is small and the mobility of carriers is high as well as the concentration of holes near the drain is high. As a result, the transistor has an unusually low resistance on condition and this permits the high density current to flow at a low potential difference between the drain and the source. Gate currents depend on operation duty: first of all the recombination holes and electrons in the source, drain and gates define gate currents. Big hole currents flow through gates at the switching over of the transistor only: at an opening of the transistor by emission of holes from gates into lightly doped area and accumulation of holes; at a closing one by discharge of holes (extraction).

2. Supplemental duty. A hole concentration approximately is the same in the whole lightly doped area. The diffusion current is negligible. The gate disposed near the drain of the transistor emits holes into the channel and lightly doped area. The holes drift to the source of the transistor and are extracted by the gate disposed near the source. The electrons drift to meet holes – from the source to the drain of the transistor. The electron concentration equal to approximately the hole concentration. The electron current is 3 times bigger, than the hole current, owing to the electron mobility is 3 times bigger. The features of operation duty – a low current amplification factor, a high speed response.

To increase all three operating and latch currents of the transistor and voltage which can be blocked, the offered BBSITs should have the channel with a low resistance. To this end, the thicknesses of the channels should be small and the impurity concentration near the gate should be high enough so that the electronic current flowing near the gate could not cause a large voltage drop which, in turn, could lead to emission of holes. To meet these requirements, it is desirable to grow an epitaxial layer with donor impurity concentration being about 10^{17} cm.⁻³ on the surface of the lightly doped substrate having the donor concentration about 10^{14} cm.⁻³, and to have an equipment with higher resolution than is generally used for manufacturing other BSITs. The distance from the boundary of the epitaxial layer to the gate should be about 10^{-5} cm. On the surface of a monocrystal silicon a layer of a polysilicon may be disposed that would help to form the elements of the transistor: the gate, the sources, the channels and the electrodes.

There are several different ways of using the thick channel. One of them is reported below. The control signals on the gates of the transistor should depend both on a polarity of the supply voltage (as a rule, it is alternating voltage with the frequency 50-60 Hz) and on the voltage applied at the moment to the transistor; two thick channels with small current have been introduced to help to determine the value and the polarity of the voltage on the transistor at that moment. Signals from these channels are transmitted to the control circuit which produces control signals to the gates. Besides, potentials and currents applied to electrodes of thick channels with control circuit are changing the operating duty of the transistor. The thick channel source electrode occupies $10^{-5} \times 10^{-1}$ of square of the ordinary channel source electrode.

Most suitable transistors for the driver are low-voltage bipolar mode field effect transistors. Due to a small size, they have sufficiently low resistance on-condition, high gain and high speed response to control a power transistor.

In a zero approximation, the offered transistor does multiplication of voltages applied to the transistor gates and drains and can be considered as double-band modulator and can be used, for example, to control polarity of rectified voltage.

The transistor with an offered combination of features is unknown, therefore the offered transistor corresponds to a criterion "novelty".

The offered combination of features does not obviously follow from the engineering level, technical performents does not known from prior art, therefore the transistor corresponds to a criterion "invention level".

The purpose of the invention and the means and methods of its realization are indicated in the application documents, its purpose being realizable,—which means there is "industrial applicability".

brief description of the drawings

Inventions is explained with twenty one drawings.

Fig 1 represents a field effect transistor structure (prior art).

Fig 2 represents a bidirectional semiconductor device structure (prior art).

Fig.3 represents a power normally-off transistor structure with two lowpower normally-on channels; gates, sources, channels are disposed in epitaxial layers.

Fig.4 represents a symbolic image of the offered power normally-off transistor with two thick channels.

detail descreption of the preferred embodiment

Bipolar static induction transistor fig.1 comprises substrate 11, drain electrode 12, epitaxial layer 13, gate 14, gate electrode 15, source 16, channel 17, source electrode (n+-type polysilicon) 18, source contact 19, isolation 20.

Bidirectional semiconductor device fig.2 comprises substrate 21, n+ type source 22, p-type base (anode) 23, p-type anode (base) 24, n+ type source 25, terminals 26,27.


Bidirectional bipolar static induction transistor fig.3 comprises lightly doped n.sup.- type substrate (area) 28, gates 29, silicide gate electrodes 30, thick channels 32, thick channel sources 33, thick channel source electrodes (n+ type polysilicon) 34, silicide thick channel source contacts 35, ordinary channels 36, ordinary channel sources 37, ordinary channel source electrodes (n+ type polysilicon) 38, silicide ordinary channel source contacts 39, isolation 40, epitaxial layers 42.

Symbolic image of power normally-off transistor with two lowpower thick channels fig.4 comprises gates 55,56; sources of lowpower channels 57,60; sources of a power transistor 58,59.

Improvement of characteristics of the transistor can be achieved by cooling of one.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and detail may be made therein without departing from the spirit and the scope of the invention.

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